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OPERATIONS RESEARCH FOR WESTERN CANADIAN COAL MINES

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OPERATIONS RESEARCH FOR WESTERN CANADIAN COAL MINES

by

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ABSTRACT

Operations research includes the application of systems analysis to mining operations, the acquisition of field data and the creation and verification of computer models of these operations. These activities result in the generation of computerized mine planning tools which have a firm base in observational facts.

The Surface Mining Laboratory of the Canada Centre for Mineral and Energy Technology (CANMET), in Devon, Alberta has been engaged in operations research activities since 1982. The work includes computer simulation of truck/shovel, continuous mining equipment and dragline operations. Other examples include co-operative programs with industry (such as the demonstration and evaluation of an integrated truck management system), the development of a device to measure off-highway truck rolling resistance, and an automated remote data transmission network.

The presentation outlines existing and proposed research projects of the Operations Research group.

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RECHERCHE OPÉRATIONNELLE EN VUE D'AMÉLIORER LES TECHNIQUES
D'EXPLOITATION DANS LES MINES DE CHARBON DE L'OUEST CANADIEN

par

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RÉSUMÉ

Les activités de recherche opérationnelle comprennent l'application de l'analyse fonctionnelle dans les opérations minières, la compilation de données sur le terrain et la création et la vérification de modèles assistés par ordinateurs. Ces activités donnent lieu à la mise au point d'instruments informatisés, élaborés à partir de faits observés, pour établir un programme d'ordonnancement des activités liées à l'exploitation minière. Le Laboratoire d'exploitation minière à ciel ouvert du Centre canadien de la technologie des minéraux et de l'énergie (CANMET), situé à Devon en Alberta, s'adonne à des activités de recherche opérationnelle depuis 1982. Les activités comprennent la simulation assistée par ordinateur d'un camion/pelle, la mise au point d'un équipement d'exploitation minière en continu et les opérations de pelle à benne traînante. Elles peuvent également inclure des programmes exécutés conjointement avec l'industrie (comme par exemple, la démonstration et l'évaluation d'un système d'information de gestion intégré des camions), le développement d'un dispositif pour mesurer la résistance au roulement des véhicules tous-terrains, et un réseau automatisé de transmission des données à distance.

L'exposé porte sur les projets de recherche en cours ou que projette de réaliser le Groupe de recherche opérationnelle.

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INTRODUCTION

Western Canadian surface coal and oil sands mines can be subdivided into:

- metallurgical coal mines close to Rocky Mountains,
- thermal coal mines on the prairies, and
- oil sands mines in the Athabasca tar sands area of Northern Alberta.

These different types of mines have different research requirements. Metallurgical coal mines tend to work with complex geologies, complex mine plans and uncertainty of the market. Their needs thus revolve around short to medium term problems and optimization. The mines of the prairies by contrast have a good knowledge of their geology and production requirements. Their research need is thus the optimization of long term strategies, selection of large mining equipment (draglines, etc.) or the introduction of new mining technologies (bucket wheel excavators or other continuous mining machines). The oil sands mines are very large operations by comparison with most coal mines. They tend to be concerned with security of supply and have extensive on-site expertise in many areas. Projects here tend to be long term and deal with well defined aspects of the operations.

The objective of the Operations Research group is to apply scientific methods of analysis to the management and deployment of surface mining equipment. Examples of the type of activities related to this research include system analysis, data gathering, time studies, and computer simulations of mining equipment.

- The benefits to industry of the operations research activity include:
- from systems analysis, one may obtain a keener sense of the critical aspects of unit operations,
 - from the data acquisition process participating mines obtain a very accurate picture of their operations, that may highlight areas of potential improvement, and
 - from modelling and validation efforts industry obtains a tool that is proven for Canadian conditions and that can be used for planning and scheduling purposes.

Additionally monitoring technology is obtained or developed for the data acquisition activity that can be used in the equipment management process.

WORK IN PROGRESS

The objectives of operations research are straight forward: to provide the knowledge to make informed judgment in the medium and long term, and to provide a mechanism where the operations are controlled and optimized in the short term. In practical terms this involves data acquisition and monitoring, system analysis, modelling and finally the use of this information for planning and operations control.

Truck/Shovel Modelling

A steady-state model of a truck/shovel operation has been completed and validated. This model was jointly developed with the National Research Council in Ottawa (Nenonen, 1982). The model includes data files from eight western Canadian coal mines, nine loader/shovel manufacturers, and eight off-highway trucks manufacturers. A user friendly data entry package will match mine conditions with selected loading and hauling equipment to provide best route selection or best equipment match for particular user defined scenarios.

The dynamic event-based model developed uses data provided by a steady-state model and may be used for short or long term mine planning, to investigate problems and practices which affect equipment operating cycles and dynamic equipment interaction.

A module, containing various knowledge-based sub-modules and expert guidance systems, is under development (Srajer et al, 1986). The system will assist users in proper and efficient use of other modules, and will utilize menus and prompts designed to carry out the particular tasks.

Continuous Mining Modelling

An event-based model of BWE/conveyor/bin operation was developed by the National Research Council in Ottawa and validated (Monenco, 1986). The model operates on an event-by-event basis, various types of excavator cuts are analysed separately. The model input data consists of bucket wheel excavator parameters, time variables, and geological data. Output reports such as initial conditions reports, production summaries, performance indicators, time statistics, histograms, time histories and graphical displays are produced by the program. During validation of the model the documentation and general adequacy of the software was examined and tested (using data supplied by mining companies) by comparing calculated values with actual data.

Another continuous mining system module, to simulate activity of the Easi-Miner machine, was developed as an alternative loading module of the truck/shovel model (Griffin et al, 1987). The user has the ability to choose the continuous mining system module as an optional loading system. The measure of operation performance is the production rate. A stochastic simulation is used to reflect the random variation in duration of continuous miner and trucks activities. Data were collected from an operating mine by time studies and analysis of production records.

A software package/program for the numerical evaluation of conveyor belt lengths as a function of the installed power was developed to calculate the maximum permissible length of a single flight conveyor (Szymanski et al, 1987). A set of tables and plots are produced to give the user an opportunity to do quick calculation and estimates.

Dragline Modelling

An interactive computer model of dragline operations has been developed for modelling oil sands mining (Graefe, 1982). From the

orebody description and mining selectivity, layers of ore and reject are determined and mined by the dragline. The model allows for the presence of pads as a dragline base, key cuts and a number of interruptions to the mining operation. A CRT display keeps the model operator informed about equipment status and performance. The operator may direct the course of simulation by issuing commands to the model at any time during the simulation. The model was tested by using data supplied from an actual mining operation.

A computer program, purchased from MRE Ltd. of Kingston, Ont., was used to examine problems in dragline selection for one mining company and to analyse different dragline mining methods. The program was validated with actual field data and used to analyse several alternatives of pit configuration and equipment requirements.

A study was completed to examine two approaches to the development of computer simulation of dragline operations: the use of interactive graphics and expert systems were compared for a common surface mining problem, planning of dragline operations. An interactive, graphical program was used to produce an animated dragline which is manipulated on the screen until the operator has produced a satisfactory solution (Stuart, 1988). The second program uses the features of the Prolog programming language to select sets of input values and criteria for eliminating unacceptable solutions. The program then lists all possible mine designs that meet the criteria.

Field Monitoring

The ability to predict equipment performance from a model and the ability to monitor accurately the actual performance of equipment in the field, are complementary activities. The models developed are based on and verified against field data. Consequently there are two purposes to equipment monitoring: as input data for a predictive model and as review information for equipment management. In practice the data collection procedure is the same for both.

The collection of mine site specific equipment performance data for the variety of conditions encountered in Canadian surface mines is a complex and expensive process. While the Operations Research group is committed to the collection of such data the support of industry mine site personnel is essential.

A total of eight surface coal mining companies in Canada cooperated in data collection for development and validation of a truck/shovel computer model (Srajer, 1985). Dragline performance data was collected at two mining properties and used for equipment analysis (Srajer et al, 1985). A review of existing data collection and truck management systems (Srajer, 1986) was completed and led to a joint demonstration and evaluation of an integrated truck management system with Gregg River Resources mine in Hinton, Alberta. This project is described later in the paper.

A study of truck performance and sensitivity of mine profitability to the condition of haulage roads quantified the significance of rolling

resistance and resulted in development of a simple standard device for measuring rolling resistance (Stuart et al, 1985). The rolling resistance measurement device is a single axle trailer with a compartmented water tank to vary axle weight, a towing bar/force transducer, and a data acquisition system. The significance of using realistic rolling resistance values can, through the use of computer models, more accurately predict cycle times and thus haulage requirements. Also the additional data will allow an economic model to be built on the effect of roadway construction and maintenance practices on overall haulage economics, allowing optimization.

Data acquisition initially constituted time studies using stop-watches. Later, new microprocessor based data loggers were customized to record events and other data. At the end of the shift the data is downloaded, either directly onto a personal computer or by modem to the Laboratory's mini computer which is used for data analysis. The Laboratory has been involved with automated monitoring systems for many years; the evolution of technology is discussed elsewhere (Stuart et al, 1985). One of the first systems used was the 'Conspec' environmental monitoring system developed for use in underground coal mines. The system was principally used to relay ventilation data from the active mining areas to the mine office. The Laboratory developed by contract a radio telemetry system for monitoring surface ground movements above underground mine workings (Fisekci et al, 1980). This system was custom designed to meet requirements of winter operation. It was highly optimized in terms of power consumption and the required task, but lacked flexibility for other than its original intended use. The system was later modified to monitor highwall movements at the Syncrude oil sands mine and a number of other applications have been considered. The system is now ten years old and would require significant modification to be applied to other situations. Thus the Laboratory is currently working on an updated general purpose telemetry system to be used for a wide variety of mining tasks: data acquisition, monitoring and more complex communications such as those associated with truck dispatching.

Systems Analysis

For the purpose of this paper 'system analysis' refers to the process of analytical thought applied to the observed mining activity. It involves:

1. The division of the mining process into events and activities, for example the description of the truck haulage cycle in terms of spotting, loading, hauling, etc.
2. The determination of the logical constraints governing how these must interrelate. An example here may be the interaction between trucks and shovels resulting in shovel 'idle' time and truck 'queueing'.
3. The development or selection of equations that constrain these activities in terms of physical laws, for example the algorithm for calculating truck speed in terms of road and engine characteristics.

4. The definition of the aims of the activity, such as the maximization of equipment usage, the fulfillment of mining plan objectives, etc.

The process of analysis has a purpose. It is always possible to further decompose a model to refine its similtude, however one must keep in mind the purpose of the analysis. There has been a great deal of debate internally on the detail to which models should be constructed. The issue falls into two types:

1. Would increased detail result in the model being expressed in better known quantities?
2. Would increased detail result in severe performance deterioration of the computer model?

The definition of the constraints and interaction of a system can be the most difficult activity and certainly requires the greatest amount of knowledge about the mining method. The development of equations representing physical constraints represent the input of scientific knowledge into the model. The determination of the objectives of the mining process may or may not be trivial. An example of a non-trivial objective problem is truck dispatch. In the early literature one sees attempts to optimize truck utilization with the results that trucks perform unnecessary travelling, or to optimize production with the result that closes shovels are over serviced. In general the aims of a mining operation involve reconciling short, medium and long term plans, the priority of which may change for a number of reasons.

The Laboratory's projects involving system analysis have been on a variety of scales. Smaller projects, such as the dragline modelling project currently underway, are relatively straight forward and are performed in-house. In other cases the analysis, the definition of model requirements, model building and its validation has been overseen by other organizations working under contract or in cooperative ventures.

COOPERATIVE RESEARCH

The Surface Mining Laboratory research program in operations research was initiated as a result of strong indications of industry support. To date industry has provided assistance in model development, has supplied and assisted in the collection of field data and has in some cases provided direct financial support to particular projects.

Successful continuation of the work is dependent upon industry support and active cooperation. The intent of the work done by the Operations Research group is to produce outputs that are relevant to the needs of industry. Such relevance is best ensured by continuing close working relationships.

Two major cooperative projects are presently underway:

- demonstration and evaluation of On-board Data Acquisition System with Gregg River Resources in Hinton, Alberta, and
- development, demonstration and evaluation of Integrated Truck/Shovel Operating and Management System with Wenco Int. of Vancouver, B.C.

The On-board Data Acquisition System (OBDAS) was installed on two Euclid R-170's off-highway trucks operating at the Gregg River mine and tested for the period of six months, starting in January, 1987. During this time a series of studies were carried out to test the reliability, accuracy, and repeatability of the system. It was concluded at the completion of the project, that the system proved to be dependable, accurate and can provide productivity and cost improvements to the mine haulage function. The installation of the OBDAS system on two trucks has resulted in overall saving of \$ 240,000 annually in handling 12 Million BCM of waste (Gould et al, 1988). This calculation is based on increased truck productivity since the OBDAS system was introduced. The average load per cycle for OBDAS equipped trucks increased from 55.3 to 57.3 BCM. The initial capital expenditure was \$ 60,000 for hardware installed on two trucks plus radio communication. Equipping the remaining six trucks in the waste haulage fleet will add another \$ 100,000 to the capital cost. Because the weigh studies indicate that the two trucks having OBDAS are carrying a greater payload than trucks without OBDAS, expanding the system to cover the entire fleet should further increase savings. The system also demonstrated the ability to develop the information base and real time monitoring needed to develop a dispatching system. The microprocessor used is also able to accept additional input that could increase its use as a maintenance monitoring and planning tool.

The Integrated Truck/Shovel Operating and Management System is in the initial stage of development. The project commenced in April 1988 and is proposed to be complete in three years. The system consists of six different components:

1. Computer Simulation Program

This program is intended for short to medium term production scheduling and is expected to be developed in several modules that may be used independently. The program will accept real time data generated and collected by various mine site equipment and other information systems and drive the dispatching program.

2. Dispatching Program

This program must dispatch trucks in real time in accordance with a variety of mine site policies. It is proposed that the dispatching system be set up at the beginning of each shift, monitor truck/shovel performance in relation to this basic set-up, and reassign in keeping with specified mine site requirements. This system must allow for user interaction at anytime, and provide trend information as specified by the user.

3. Equipment Information System

This system, with appropriate software, is expected to monitor relevant operating, maintenance and equipment performance data and

feed this data for further processing in the simulation and dispatching programs. Types of data covered by this information system are expected to be defined by the producing mining companies.

4. Data Transfer System

A radio based two way communications system that can send monitored information to a central computer for processing, and relay dispatch decisions as well as provide voice communication is an example of such a data transmission system. The system must provide temporary on-line storage of data for "on-demand" transmission and further processing and data transmission accuracy checking.

5. Mobile Equipment Location Devices

This component will locate and continuously update equipment location using satellite or terrestrial based facilities. This automatic vehicle location system is defined as an assembly of technologies and equipment that permits centralized and automatic detection and display of the position and movement of equipment through an area. The results of this system component will be integrated into the simulation program that drives the dispatching module. Other uses of the vehicle location system may be defined by the user.

6. Data Base System

This component is the heart of the system. Format and storage approach must facilitate effective access to the data for a variety of purposes not limited to those included in this technology demonstration program.

In essence the computer simulation program will take equipment information and location system outputs relayed by the data transmission system, conduct simulations, apply the logic of the dispatch program and inform equipment operators of dispatch decisions.

The central computing facility may also subject the collected data to other analyses to provide operating, management and maintenance information. The data base system must recognize and be responsive to future incremental and new uses.

CONCLUDING REMARKS

This paper has outlined the current status of Operations Research activities at the Surface Mining Laboratory of CANMET, in Devon, Alberta. At the beginning of the research work, a five year plan was developed and presented for industry comment and review. All elements of the work were subject to modification as a result of industry input. Presented and described research activities are strongly supported by various mining companies in Canada. Most of the work is done as joint industry-government sponsored projects that address immediate and longer term industry needs.

The nature of the impact of a project is variable. One project may present an operator with a site specific model and time study data of their operation which is not directly transferable to other mine sites

(ie. would require modifications and incremental time study data). Another case is the software developed to determine the power requirements of a conveyor belt. The work is generic and the impact is harder to assess through presumably wider. There is an inherent conflict between the desire to produce 'generic' results and the closer cooperation with industry through cost sharing that tends to centre on site specific problems and greater use of confidential data.

The output of the Operations Research group takes many forms: confidential reports or scientific publications, site specific computer models or public domain software and projects that demonstrate state of the art hardware followed by debriefing seminars to which the industry is invited.

Development of software has dominantly been Fortran based. However, software tools, such as 'Anevent' simulation library, or recently 'Slam' simulation language have been used. Modula 2 has been used lately in-house for data acquisition software. There are a number of capabilities that Modula has over Fortran, however its main advantage has been in enforcing readable structured code. Some experimental programs have been written in the 'Prolog' programming language. A program written in 'Prolog' that expresses truck dispatching rules as a set of logical statements was converted into a simulation program by the addition of a few extra lines.

Accomplishment of all tasks requires and will continue to require strong support and cooperation from industry. The pace and directions of work will continue to be strongly influenced by industrial needs and evidence of willingness to participate in the conduct of the work.

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REFERENCES

- Fisekci, M.Y., Chiang, C., Bannerman, W., "Update in the Hydraulic Mine Strata Studies in Thick and Steep of Rocky Mountain", Proceedings of the 21st U.S. Symposium on Rock Mechanics, Rolla, Missouri, August 1980.
- Gould, G.B., McConechy, B., Srajer, V., "Equipment Performance Monitoring", Proceedings of the First Canadian Conference on Computer Application in the Mineral Industry, Quebec City, Quebec, May 1988.
- Graefe, P.W.U., "Interactive Computer Modelling of Draglines", 84th Annual General Meeting of CIMM, Quebec City, Quebec, April 1982.
- Griffin, W.H., Szymanski, J.K., "A Simulation Analysis Model for Continuous Surface Miner and Trucks Operation Using Slam II", SML Division Report ERP/CRL 87- (TR), 1987.

- Monenco Consultants Ltd., "The Assessment, Evaluation and Validation of a Computer Based Simulation Model", Final Report, DSS File No. 03.SQ. 23440-5-9249, Sept. 1986.
- Nenonen, L.K., Graefe, P.W.V., Chan, A.W., "Interactive Computer Modelling of Truck Haulage Systems", 84th Annual General Meeting of CIMM, Quebec City, Quebec, April 1982.
- Srajer, V., Stuart, N.J., "The Study of Dragline Operation at Highvale Mine in Alberta", SML Division Report ERP/CRL 85-94 (TR), 1985.
- Srajer, V., "The Computer Modelling of Surface Mining Operations", First IFAC Symposium on Automation for Mineral Resource Development, Brisbane, Australia, July, 1985.
- Srajer, V., "A Review of On-board Truck Management Systems", 3rd Conference on Use of Computers in the Coal Industry, Morgantown, W.V., July 1986.
- Srajer, V., Kolada, R.J., Stuart, N.J., Szymanski, J.K., "Operations Research Discussion Document", SML Division Report ERP/CRL 86-68 (OP), 1986.
- Stuart, N.J., Kolada, R.J., "A Strategy for Measuring Off-highway Truck Rolling Resistances", Division Report ERP/CRL 85-106 (TR), 1985.
- Stuart, N.J., Cobb, Q., "Two Approaches to the Computerized Planning of Dragline Operations", 1st Canadian Conference on Computer Applications in the Mineral Industry, Quebec City, Quebec, March 1988.